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ORIGINAL ARTICLE

Videofluorographic Evaluation of Mastication and Swallowing of Japanese Udon Noodles and White Rice

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Abstract A videofluorographic (VF) swallowing study was performed on 22 healthy volunteers to observe the complete mastication and swallowing phases for Japanese udon noodles and white rice. The hardness, stickiness, and cohesiveness of food samples were measured using a food texture analyzing system. VF images were acquired using a versatile fluoroscopic unit and barium sulfate was used as a contrast medium. Udon noodles had a harder and smoother food texture than white rice. Fewer chewing movements and more stage 2 transport were seen during the consumption of udon noodles than for white rice.

Keywords Deglutition · Deglutition disorders · Videofluorographic swallowing study · VF · Food texture · Stage 2 transport

Swallowing disorders are common, especially in the elderly, and may cause dehydration, weight loss, aspiration pneumonia, and airway obstruction. Swallowing disorders include a number of diseases and conditions that cause difficulty in transporting food or liquid from the oral cavity to the esophagus [1]. In severe cases, the patient may need a feeding tube that bypasses the part of the swallowing system that does not work. In a large number of cases, special liquid diets may be necessary for patients who continue to have trouble masticating or swallowing.

In our clinical experience we have found that clinicians receive inquiries from patients or caregivers about the provision of a patient's favorite foods. Udon noodles and white rice are the traditional staple diet of the Japanese. Past studies of the swallowing movement have shown that a bolus never enters the pharynx before the swallowing reflex occurs. However, recent studies have revealed that a preswallow bolus of chewed food can be transported from the oral cavity to the oropharynx before the swallowing reflex. This transportation is one of the varieties of normal swallowing, and is called stage 2 transport [2–4]. There have been several reports regarding videofluorographic (VF) swallowing study findings of food bolus formation and transport during complete feeding sequences for various foods, including mastication and swallowing. Although Western foods such as bread and cookies have been studied, oriental foods such as cooked white rice and udon noodles have not been evaluated yet. Therefore, the aim of the present study was to evaluate the normal VF findings during complete mastication and swallowing phases for Japanese udon noodles and white rice.

Materials and Methods

Twenty-two volunteers (6 males and 16 females, aged 19–38 years, mean age = 22.4 years), who did not have a history of swallowing disorders, were enrolled in this study. The study design was reviewed and approved by the ethics committee of our institution. Informed consent was obtained from each volunteer before the VF images were taken.

Udon noodles and cooked white rice with barium sulfate contrast medium were prepared (Fig. 1). The textural properties of the test foods were assessed using a texture analyzing system (RE-3305S, YAMADEN, Japan). A two-bite test of each sample was performed with a cylindrical

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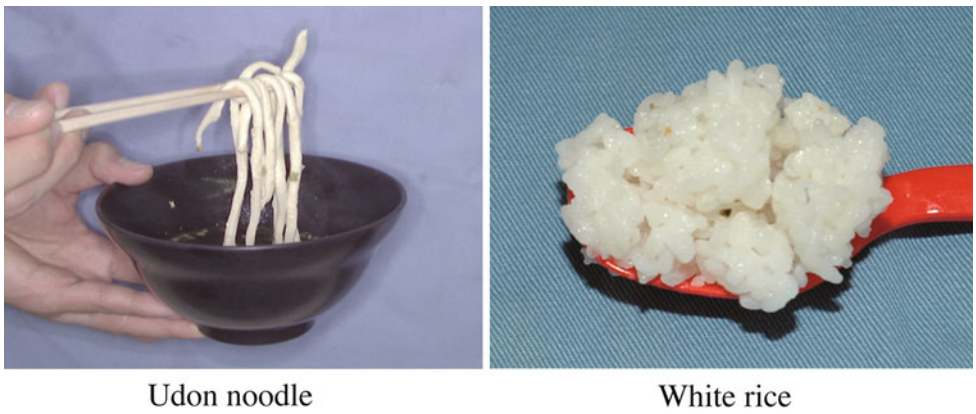


Fig. 1 Udon noodles and white rice

plunger (10 mm in diameter). The speed of the plunger was 1.0 mm/s and the final sample deformation was set at one third of the original height of the sample. From the data of the compressive load, the software calculated the hardness, stickiness, and cohesiveness of the samples. Five measurements were taken for each sample.

Volunteers sat on a special VF chair (Tomomi Kobou Inc., Japan) and lateral X-ray images were taken using a fluoroscopic unit (Finescope300, TOSHIBA, Japan). An automatic brightness control mode was used to adjust the X-ray exposure factor and the gain of an image intensifier detector. Each volunteer ate a morsel of test food in a manner of his/her choosing. The weight of the morsel of test food had been measured. Fluoroscopic images were recorded on digital videotape (SONY, Japan) and imported into a computer system (Mac Pro, Apple, USA) to observe and evaluate images.

The items measured from the VF images were (1) the number of chewing strokes until the first swallow motion occurred, (2) time between the beginning of mastication and the end of swallowing, (3) the number of partitioned swallows until the entire food bolus was cleared from the mouth, and (4) the frequency and degree of stage 2 transport of the food bolus.

Based on previous reports [2–4], the degree of stage 2 transport of the food bolus is classified as follows (Fig. 2): (a) the bolus remains in the oral cavity until the start of the swallowing reflex without stage 2 transport, (b) the leading edge of the forming bolus passes across the pillars of the fauces before initiation of the swallow on the way to the lower border of the mandible, (c) the leading edge passes across the lower border of the mandible on the way to the valleculae, and (d) the leading edge is at the area between the valleculae and the piriform sinus (entrance of the esophagus).

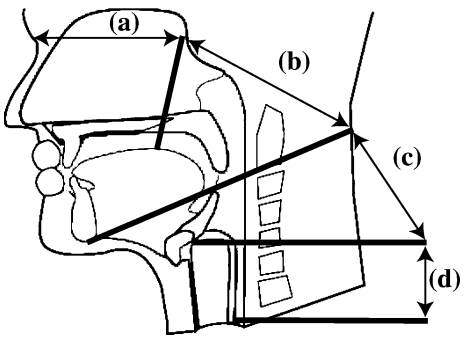


Fig. 2 Classification of the degree of stage 2 transport: (*a*) oral cavity, (*b*) between the pillars of the fauces and the lower border of the mandible, (*c*) between the lower border of the mandible and the valleculae, (*d*) between the valleculae and the piriform sinus

Differences between udon noodles and white rice were statistically analyzed using Student's *t* test and Wilcoxon signed-ranks test, and significance was set at $P < 0.05$.

Results

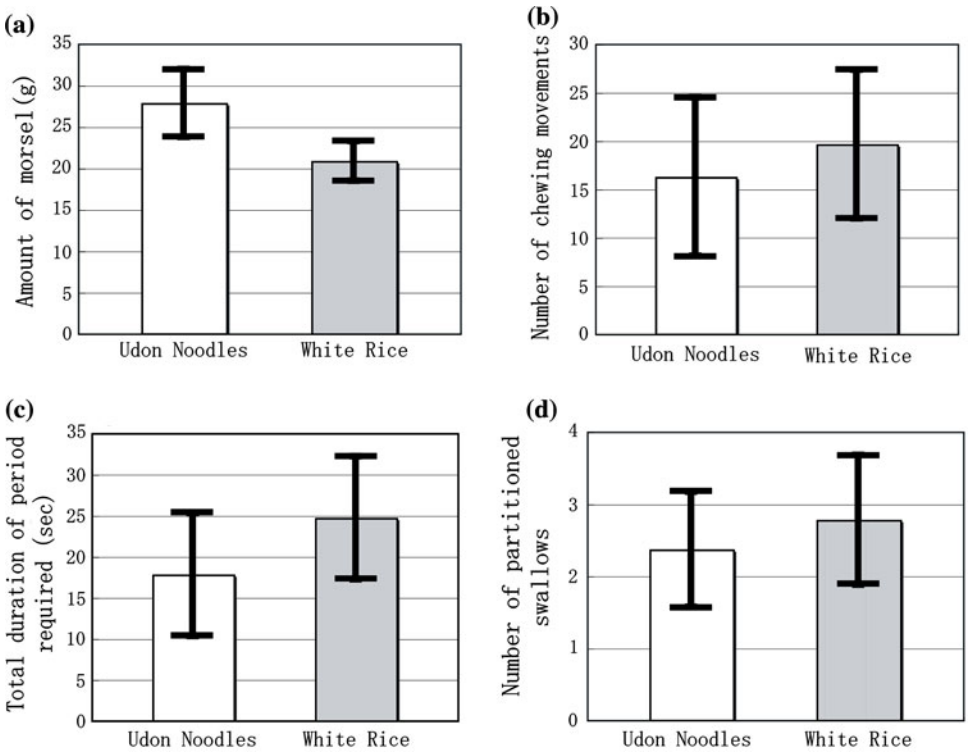
Table 1 gives the instrumentally measured textures of udon noodles and white rice. Udon noodles were harder but less sticky than white rice. There was no substantial difference in cohesiveness between the two foods.

The mean weight of a mouthful of food was 21.0 ± 2.7 g for the cooked white rice and 27.8 ± 4.1 g for the udon noodles. The mean number of chewing movements was 19.5 ± 7.7 for the white rice and 16.2 ± 8.2 for the udon noodles. The total duration of the period required to eat the white rice was 24.7 ± 7.5 s and that for udon noodles was 17.7 ± 5.5 s. There were significant differences ($P < 0.05$) between the two foods for the above three variables. Regarding the mean number of partitioned swallows, the recorded value was 2.7 ± 0.9 times for the white rice and 2.3 ± 0.8 times for the udon noodles. There was no significant difference between these values. Graphs to summarize

Table 1 Instrumentally measured textures of udon noodles and white rice

Texture	Udon noodles	White rice	*P*
Hardness (kPa)	10.8 ± 1.7	7.0 ± 0.5	**
Cohesiveness	0.91 ± 0.01	0.84 ± 0.03	*
Stickiness (J/m^3)	24.1 ± 10.3	41.1 ± 23.5	*

* $P > 0.05$; ** $P > 0.01$, significantly different by Student's *t* test



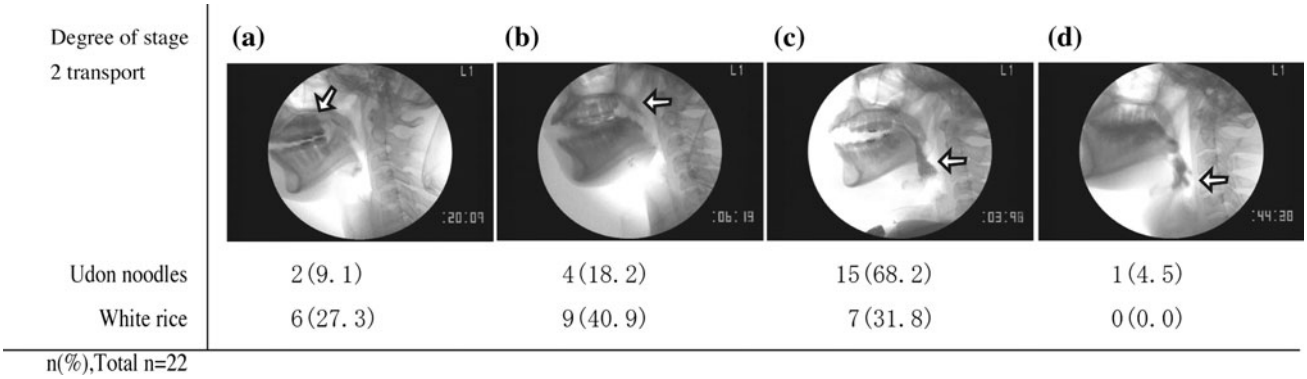


Fig. 3 Graphs comparing udon noodles and white rice. **a** The mean weight of a mouthful of food. **b** The mean number of chewing movements. **c** The total duration of the period required to eat. **d** The mean number of partitioned swallows

Fig. 4 Prevalence and degree of stage 2 transport. More stage 2 transport was observed for udon noodles than for white rice

the results from the VF studies of the two foods are shown in Fig. 3.

Swallowing with stage 2 transport was seen more frequently while eating udon noodles than white rice. The degree of stage 2 transport of the food bolus is shown in Fig. 4. Stage 2 transport was observed in approximately 70% of swallows for the white rice and 90% of swallows for the udon noodles. The leading edge of the udon noodle bolus reached deeper into the pharynx than that of the white rice.

Discussion

Several studies have reported that food consistency affects feeding behavior, including chewing and swallowing [1–4]. Taniguchi et al. [5] suggested that the major effect of food hardness was to delay oral ejection time, which strongly extends total swallowing time. They also mentioned that pharyngeal bolus transit is not dependent on the hardness of food but rather on its viscosity.

It has been shown that large differences exist among foods with respect to whether mastication before swallowing is necessary. For example, chewing movements should appear when a subject eats a solid food such as cooked white rice. However, chewing movements do not always appear when a subject eats a paste of pudding-consistency food.

Chewing is the first step in the process of eating and is meant to prepare the food for swallowing. During chewing, the saliva moistens the food bolus and binds masticated

food into a smooth bolus that can be easily swallowed [6]. The urge to swallow can be triggered by a threshold level in both food particle size and lubrication of the food bolus [7, 8]. In our study, the number of chewing movements for udon noodles was smaller than that for white rice. This may be due to the higher moisture content of udon noodles, because they are usually served as a noodle soup. In addition, udon noodles are less sticky than white rice. Udon noodles generally appear to be easy to swallow; however, they may be not easy to eat for patients with dysphagia. Regarding the texture of these Japanese foods, the approximate hardness of both udon noodles and white rice was between pudding and cookies subjectively. Texture measurement revealed that the udon noodle is harder than white rice. In addition, udon noodles are long and thin. These properties mean that the volume of a mouthful of udon noodles is larger than that of white rice. The usual way to eat udon and soba noodles is unique to Japan. Unlike spaghetti, these noodles are usually eaten with soup. The unevenness in the texture of food is critical for patients with dysphagia, especially a meal that is a mixture of liquid and solid.

In the present study, stage 2 transport was observed more frequently for udon noodles than for white rice. It has been reported that various factors such as food consistency, duration of chewing, and head position affect the frequency and degree of stage 2 transport [9, 10]. In the theory of stage 2 transport, two processes can occur concurrently when feeding on solid food: chewing and transport to the hypopharynx. This transport to the hypopharynx is highly dependent on gravity. Chewing appears to reduce the effectiveness of the posterior tongue-palate seal, allowing oral contents to spill into the pharynx. We think that the stage 2 transport in udon noodle feeding is due to the larger volume of a mouthful and the particularly long and thin shape of udon noodles. Although the bolus of udon noodle penetrated deeper into pharynx, it was difficult to distinguish between active stage 2 transport and stage 2 transport-like bolus penetration into pharynx correctly from only VF images. In our clinical VF study experience, we have observed quite a few cases where stage 2 transport occurred in patients with dysphagia. It is difficult for elderly dysphagic patients to consume solid food for which chewing is necessary. A regular diet may increase the risk of aspiration in dysphagic patients with impaired airway-protective reflexes.

As an alternative to white rice, rice porridge, also known as gruel, is the most common soft and easy-to-swallow foodstuff used in hospital meals. Okazawa et al. [11] reported on the properties of rice porridge (gruel) as a meal for patients with swallowing disorders and suggested that the texture of gruel should be prepared according to the conditions of each dysphagic patient. To feed on udon noodles safely, a special food-softening technique, such as an enzyme infusion method, may be useful [12].

Conclusion

Food texture and VF findings during feeding on udon noodles and white rice were studied. It was revealed that there were several differences between the two foods in terms of bolus formation and pharyngeal transport during complete feeding sequences.

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